VULNERABILITY AND BUILDINGS SERVICE LIFE APPLIED TO PREVENTIVE CONSERVATION IN CULTURAL HERITAGE

Purpose

This paper presents research on vulnerability and service life indexes applied to cultural heritage buildings. The construction and rehabilitation industry is concerned with the maintenance of monuments and reducing the economic costs of urgent interventions by taking preventive conservation action in historic cities. By applying a vulnerability index or analyzing the service life of buildings, it is possible to reduce risk and optimize the identification, evaluation and prioritization of urgent monument restoration tasks in a city or a region in order to establish preventive conservation policies.

Design/methodology/approach

This research sets out the concepts of vulnerability and service life, focusing on their methodologies in comparison with other techniques for building diagnosis, discussing the differences between indexes that measure the vulnerability and service life of buildings.

Findings

The vulnerability of three churches in Seville (Spain) was studied by means of their vulnerability index, based on Delphi analysis, and the service life of these buildings was also assessed, based on artificial intelligence tools. Delphi and artificial intelligence tools allow us to compare and dovetail different scenarios and expert opinions. The degree of each monument’s conservation is defined as its

vulnerability index, which is an indirect function of deterioration levels. The service life of buildings, on the other hand, includes the assessment of vulnerability and hazards.

Practical Implications

This study is useful for stakeholders, including SMEs and policy-makers, as an important reference on diagnosis, including updated, inexpensive and sustainable methodologies to manage the conservation of monuments, which are easy to implement in developed and developing countries.

The application of vulnerability and/or service life indicators is crucial to ensuring the sustainability and improvement of maintenance carried out on cultural heritage buildings.

Originality/value

New approaches based on artificial intelligence and Delphi analysis to prioritize preventive conservation actions in a city or region.

Keywords: Vulnerability, Risk analysis, Hazard mapping, Monument, Preventive conservation, Delphi and Artificial intelligence tools

1. INTRODUCTION

The term 'diagnosis' in the preservation of cultural heritage can be described as knowing the symptoms and diseases of monuments in order to design appropriate interventions and maintenance projects. Preventive conservation measures, on the other hand, can enhance the resilience of monuments against threats (hazards), reducing vulnerability or alteration agents to minimize risks.

Preventive conservation reduces high-cost cultural heritage interventions and allows monuments to be preserved for future generations in accordance with a sustainable strategy.

Since the Council of Europe established its recommendation on architectural heritage protection against natural disasters in 1993 (Consejo de Europa, 1993), risk and vulnerability assessments have gained much attention in developed and developing countries, because disasters such as earthquakes, floods, fires, etc., have a major impact on the conservation of cultural heritage sites and the economic development of cities. Moreover, climate change and pollution have exacerbated common environmental conditions, such as wind erosion, dampness, etc., increasing the degradation rate of building materials and the cost of maintenance.

Unfortunately, alteration agents act in conjunction, and for this reason, new multi-scenario approaches that take into account both kinds of agents - disasters and the ravages of time - are required. In fact, each building has a defined location with multi-scenario risks as a combination of hazards and vulnerability where influences must be studied (Ortiz et al., 2014).

Multi-scenario analysis was initially studied in collections, archives and museums (Anderson and Mcintyre, 1985; Lyall, 1988; Waller, 1994; Ashley-Smith, 1999). Whole monuments or city studies are a great challenge that is analyzed in the main risk assessment of single scenarios (Stovel, 1998; Vis et al., 2003). Nevertheless, new approaches are currently being developed to analyze risks for monuments or archaeological sites (Ortiz et al., 2014; Zivkovic, 2012; Paolini et al., 2012), with a huge volume of data and scenarios, which require models to be simplified for decision-makers.

RIVUPH and ART-Risk methodologies are new approaches based on multidisciplinary analysis of environmental risk in historic cities or regions that seek to develop global urban conservation strategies capable of minimizing the deterioration of monuments and reducing the cost of isolated interventions against hazards through urban plans and preventive conservation actions (Ortiz et al., 2016a).

The aim of this paper is to present applied research on vulnerability and the service life of buildings in order to contribute to the preservation of cultural heritage, allowing local and regional bodies to make decisions about conservation based on scientific criteria. Both models compare different monuments, their vulnerability and risks in order to prioritize restoration and preventive maintenance measures.

Our models aim to ascertain the risks by means of a multi-stage system and to evaluate them in terms of the vulnerability of the monument (as degree of health or disease), or functionality (as service life). The tools are based on DELPHI expert panels and artificial intelligence to compare diagnosis of a set of monuments with constructive similarities, assess their vulnerability, evaluate environmental conditions, and allow decisions to be made regarding investment and budgets for intervention and preventive conservation.

In this paper, we present two models: Art-Risk-1 and Art-Risk-2. Art-Risk-1 is based on the Delphi methodology, which allows us to calculate the Vulnerability Index and Expanded Vulnerability Index (Ortiz and Ortiz, 2016). Art-Risk-2 is based on Fuzzy Logic that allows us to calculate a building's service life (Macías-Bernal et al., 2014; Prieto et al., 2016). An overview of both methods and their results is provided, and comparison with other diagnostic methodologies is discussed to establish the differences between vulnerability and service life.

By applying both tools – vulnerability index and service life – it is possible to establish a way to reduce risk and optimize municipal or regional budgets for monument maintenance, reducing the economic costs of urgent interventions through the application of preventive conservation actions in historic cities.

2. METHODOLOGY

Both projects, RIVUPH (https://www.upo.es/tym/en_rivuph.html) and Art-Risk (https://www.upo.es/investiga/art-risk-en/index.html), were initially based on the methodology developed by Galán et al. (2006) in Spain for the analysis of vulnerability, and the model of territorial risk analysis developed by Pio Baldi (1991) for Italy. Guided by these principles, expert opinion consultation has allowed us to develop new criteria based on the Delphi method (Art-Risk-1 Model) and artificial intelligence (Art-Risk-2 Model).

Delphi methodology (Art-Risk-1 Model) was used to consider the hazards and vulnerability of monuments in Seville (Ortiz and Ortiz, 2016; Ortiz, 2014; Ortiz et al., 2016b) in order to obtain risk maps as an overlapping of hazards and vulnerability maps. Seven experts with experience in cultural heritage analyzed the effects of different types of damage on cultural heritage monuments (hazards) and vulnerability variables. This procedure, applied to vulnerability analysis, has allowed us to modify Leopold's double entry matrix according to the methodology for assessing environmental impacts developed by Galán et al. (2006).

The diagnosis constitutes the qualitative vulnerability matrix that flags and identifies the relationships found between environmental conditions and the degree of conservation of historic centres. Experts must carry out a visual inspection of weathering forms on site according to the ICOMOS glossary (ICOMOS-ISCS, 2008) and the 1/88 standard (CNR-ICR, 1990). The diagnosis is completed with sampling for the characterization of materials and weathering forms, interviews with stakeholders (owners, priests, sacristans, brotherhood members …), protection level data, restoration information and other external data.

Vulnerability is the degree of disease or health of a monument. The vulnerability index (VI%) and the expanded vulnerability index (VIe%) for each monument were determined by the frequency and weathering degree of the deterioration patterns (Ortiz and Ortiz, 2016), while expanded vulnerability also took into account the data from the vulnerability index and included information about the type of building, its cultural value and the level of usage.

After studying the weathering forms, the vulnerability index (VI) was calculated (1) according to Ortiz et al. (Ortiz et al., 2014).

$$VI = \frac{Vx}{\sum_{f=3} vdp} x100 \tag{1}$$

Where:

Vx is the total value of the deterioration patterns

∑vdp is the total value of deterioration patterns in the worst case scenario, at maximum frequency levels.

An expanded vulnerability index was developed according to a DELPHI assessment of the influence of different characteristics on the vulnerability matrix:

$VI_e = \sum f_i V_i$

Where:

f_i is the associated weighting factor according to DELPHI forecasting

V_i is the vulnerability associated with the variable i

Finally, the vulnerability indexes (VI% and VIe%) were classified by degree of vulnerability using the groups described by Galán et al. (2006). More than 100 monuments were classified in Seville, Cadiz, Ronda, Marchena, Osuna, Estepa, Carmona and Merida (Ortiz et al., 2014; Ortiz, 2014; Ortiz et al., 2013a; Domínguez, 2011; Benítez, 2012; Ortiz, 2012) by vulnerability index (Ortiz et al., 2013a), while 30 Churches (13th-18th Century) in the city of Seville were studied using the expanded index (Ortiz and Ortiz, 2016). This development has improved the cognitive diagram of relationships between scenarios and the vulnerability index (Ortiz and Ortiz, 2016).

In this model, hazards are classified into three categories following ICR methodology (Baldi, 1991) to develop multi-scenario hazard maps. The methodology has been improved from archeological monuments to buildings, in different cities such as Merida, Estepa and Carmona, to obtain a validated methodology that has been used to analyze different hazard maps of historic cities such as Seville, Ronda and Cadiz (Ortiz, 2015).

The second method (Art-Risk-2 Model) was developed for managing risk affecting the service life of heritage sites with homogeneous characteristics (Macías-Bernal, 2012). This new approach complies with risk management regulations (EN 31010, ISO 31000) (ISO, 2009; ISO, 2011) and the environment of inference systems based on the Xfuzzy3.0 fuzzy logic design tool (IMSE-CNM, 2012). The functionality index was developed by identifying a total of seventeen input parameters (vulnerability, static-structural, atmospheric and anthropic risk factors), validated and ranked by 15 experts, and which are related to the output parameter of the expert system: the durability of buildings (Macías-Bernal et al., 2014). 50 Churches (13th-20th Century) from the province of Seville were studied in accordance with the Art-Risk 2 Model.

Fuzzy expert systems were structured in three stages: a) “fuzzification”, in which input diagnosis values, subject to certain imprecision and subjectivity, are represented by fuzzy sets; b) “inference” stage, in which fuzzy rules are defined such as modus ponens propositional inference rules (IF “fuzzy proposal” AND “fuzzy proposal” THEN “fuzzy proposal”; and c) “defuzzification”, which is used to generate specific output values (Prieto et al., 2016; Macías-Bernal et al.,2014).

The FBSL system developed by Macias (Macías-Bernal, 2012) is supported by 5 vulnerability variables and 12 hazards that define the risks involved in the degradation of building functionality. The functionality index (FBSL) provides an orderly classification of priority actions for conservation in the form of vulnerability indexes.

For this methodology (Art-Risk2), a technical expert analyzes the service life of the buildings by means of on-site studies, interviews with stakeholders (owners, priests, sacristans, brotherhood members, …), and the collection of external data to answer questions about: a) conservation of constructive system and facilities, b) conditions of roof design, preservation, load state modification, dead and live loads, ventilation, fire and occupancy, and c) heritage value and furniture value. These opinions, added to the geological location, environmental conditions, inner environment, rainfall, temperature and population growth, allow us to calculate the functionality indexes.

The Xfuzzy3.0 free software used for this model was developed by the Institute of Microelectronics at the University of Seville in an open environment using the common specification language XFL3 (IMSE-

CNM, 2012). The new version Xfuzzy3.0 has been programmed in Java, so the software can be run on any platform, using Java-RuntimeEnvironment (JRE).

Both methodologies (Art-Risk1 and Art-Risk2) are being developed in accordance with CIB-W080 (International Council for Research and Innovation in Building and Construction) principles, based on predicting the service life of building materials and elements, with the aim of promoting international cooperation in service life prediction materials and building components, by identifying systematic methodologies related to the evaluation and estimation of service life (Haagenrud, 2004; Lacasse and Sjostrom, 2005; Lacasse, 2008; Daniotti and Cecconi, 2010).

Variables and scenarios included in both methods are compared in table 1 with some of the methodologies used in building diagnosis in order to understand the differences.

Table 1. Scenarios of analysis for different diagnosis methods.

	Ley 38/1999	CTE (Gobierno de España, 2010)	Spanish Cathedral Plan (Benito et al., 2002)	Italian Risk Map (Baldi, P., 1991)	Vulnerability Matrix (Galán et al., 2006)	UNE 41805-3 (AENOR, 2009)	ISO 15686 (ISO, 2010)	ISO 31000 (ISO, 2009)	Rehabimed proposal (Casanova, X., 2007)	Recopar proposal (Recopar, 2012)	Art-Risk-1 (Ortiz et al., 2014; Ortiz and Ortiz, 2016)	Art-Risk-2 (Prieto et al., 2016; Macías-Bernal et al., 2014)
Application												
New Buildings	X	X										
Isolated Monuments			X		X	X	X	X	X	X		
Monument-Comparison											X	X
Historical centers											X	
Risk Maps				X							X	
Variables												
Geological Location				X	X			X			X	X
Environmental Conditions			X	X	X	X		X	X	X	X	X
Inner environment				X	X	X	X	X			X	X
Rainfall				X	X	X	X	X			X	X
Temperature				X	X	X	X	X			X	X
Population growth				X				X			X	X
Roof Design	X						X	X	X		X	X
Constructive system	X	X	X			X	X	X	X	X	X	X
Preservation		X	X	X	X	X	X	X	X	X	X	X
Load state modification	X	X	X	X	X	X		X	X	X	X	X
Dead and live Loads	X	X	X	X	X	X		X	X	X	X	X
Ventilation								X			X	X
Facilities	X					X		X	X			X
Fire	X			X				X			X	X

Heritage value								X	X		X	X
Furniture Value			X					X			X	X
Occupancy					X		X	X			X	X
Noise protection	X											
Energy earn	X								X			
Economical value												
Construction date						X				X	X	
Type of building										X	X	X
Number of Variables	8	4	6	10	9	10	7	17	9	7	18	18
Percentage	36%	18%	27%	45%	41%	43%	30%	74%	39%	30%	82%	82%

Art-Risk 1 and 2 Models used about 82% of the variables and scenarios studied and are complementary in several aspects, as the first one studies building disease or health, while Art-Risk2 assesses functionality.

Technical Inspections of Buildings (Ley 38/1999, de 5 de noviembre; Gobierno de España, 2010) are used in Spain in the study of vulnerability, which vary according to local or regional law; hence, they cannot be used to compare buildings. The Technical Building Code in Spain (CTE) (Gobierno de España, 2010) [35] establishes basic conservation levels depending on the service. However, these inspections only take into account a few scenarios or variables (36-18%).

The International standard 15686:2010 (ISO, 2010) for Service Life Planning of building construction considers 30% of the variables. The Spanish Cathedral plan offers similar values (27%) while Baldi, UNE 41805-3:2009 and Galan (Galán et al., 2006; Baldi, 1991; Benito et al., 2002) take into account 41-45% of the scenarios. Our models, with 82% of the variables described above, take into account most of the scenarios, with minor differences, and comply with UNE-ISO 31000:2010 regarding principles and guidelines for risk management, although they should be improved further with the analysis of cost/benefits and energy evaluation to improve sustainability.

The RehaBimed method (Casanova et al., 2007) and Recopar recommendations (Recopar, 2012), developed by technical architects and AENOR, consider fewer variables: 39 and 30%, respectively.

Our models (Art-Risk1 and Art-Risk2) analyze the same percentage of variables, although they use different approaches based on Delphi and Fuzzy Logic and the weight of variables, and the analysis they provide seems quite different (table 2). Though most of the variables and scenarios are treated by both cases, they might be included with different loadings. Those concepts are treated as intrinsic or extrinsic variables in each method, which implies that different ways of application:

1) Fire threat is considered an intrinsic value that depends on the state of conservation of the building and an extrinsic factor that depends on the surrounding buildings in Art-risk-1 whereas Art-risk-2 only considers the fire load.

2) Change of loads and over-loads are specifically studied in Art-risk-2, whereas Art-risk-1 analyzes the consequence such as fractures, fragmentation, deformation…

3) Roof designs are specifically studied in Art-risk-2, whereas Art-risk-1 analyzes the consequence such as fractures, fragmentation, dampness, concretions…

4) All facilities (sewage and electrical systems) are studied in Art-risk-2, whereas Art-risk-1 only analyzes sewage.

5) Accessibility is treated in both models but is considered an extrinsic variable in Art-risk-1 and an intrinsic variable in Art-risk-2.

6) Protection is treated in both models but its value as an intrinsic and extrinsic variable is only studied in Art-risk-1, whereas Art-risk-2 focuses analysis on the building and its content.

Moreover, the difference in concepts, the loadings of variables, varies between 2.8 and 8.8 for the vulnerability index, whereas the range for FBSL is smaller (6.3-8.6).

One of the main differences between the two tools are the scenarios that could only be studied with one of the methods:

1) Ventilation with 6.3 of load is only employed in Art-risk-2.

2) Visual appearance as a consequence of weathering forms is only employed in Art-risk-1, perhaps due to its limited influence (load 2.8)

3) Art-risk-1 includes the hazard of seismic movement, landslide, floods, coastal dynamics, avalanches, volcanoes and underground water in its risk maps, whereas art-risk-2 does not include these scenarios.

4) Dew point and pressure of tourism are not directly studied in model Art-Risk-2 as variables.

Table 2. Intrinsic and extrinsic variables employed in the vulnerability and service life indexes, and their relationships. Indirect relationships between variables are highlighted in the same colour. Blue highlights the variables that are only treated in one model.

Art-Risk-1									Type Of Variable	Art-Risk-2		
Vulnerability										Fuzzy service life		
Source of Data		Methodology		Variables studied in the Model		Weight of each variable				Weight of each variable	Variables studied in the Model	Source of Data
Visual Inspection on site	Analysis of frequency and damage level of weathering forms	Diagnosis according Pathologies and comparison between buildings	MATERIAL	Physical-chemical characteristics		6.2		Vulnerability (Weight of vulnerability in the model (4.1)	Intrinsic Factors	8.6	Conservation	Visual Inspection on site + Interviews with stakeholders (owners, priests, sacristans, brotherhood members, …)
				Texture		4.3						
				Fire resistance		4.8						
Characterization of materials and weathering forms + Protection Level + Restoration Information + External data			STRUCTURE	Foundation		6.4						
				Structure		7.4						
				Construction	Roof	8.8				8	cover design	
					Covering	6.4						
					Sewage	6.4				Sewage is not studied in model Art-Risk-2 as Facilities		
				Condition access is studied in model Art-Risk-1 as an extrinsic variable						6.3	Condition access	
				Building simplicity		6.3				6.8	Constructive System	
Interviews with stakeholders (owners, priests, sacristans, brotherhood members, …)			ANTHROPOGENIC FACTORS	Visual appearance		2.8				Visual appearance is not directly studied in model Art-Risk-2 as a variable		
				Urban planning protection		4.3				7.1	Building cataloguing	External Data
										6.3	Art-work cataloguing	
				Level of usage		8.2				7.1	Level of usage	
Ventilation is not directly studied in model Art-Risk-1 as a variable										6.3	Ventilation	
HAZARDS				Static-structural hazards	Seismic	4.8		Hazards Weight of Hazards	Extrinsic Factors	These variables are not directly studied in model Art-Risk-2 as variables		
					Landslide							
					Floods							
					Coastal dynamics							
					Avalanches							
					Volcanoes							

	Underground water			
	Geotechnical		6.9	Geological situation
	These variables are not directly studied in model Art-Risk-1 as variables. Art-risk-1 analyzes the consequence such as fractures, fragmentation, deformation…		8	Change of Loads
			6,5	Over load
	Facilities are not directly studied in model Art-Risk-1 as variables; instead their consequence and sewage analysis are assessed.		7.4	Facilities
Environmental hazards	Rain	2.5	6.6	Rain
	Temperatures		6.4	Temperatures
	Dew		Dew point is not directly studied in model Art-Risk-2 as a variable	
	Other		5.86	Inner Environmental conditions
Anthropogenic factors	Fire	2.7	8.3	Fire safety
	Accessibility		Condition access is studied in model Art-Risk-2 as an intrinsic variable	
	Pressure of tourism		This variable is not directly studied in model Art-Risk-2 as a variable.	
	Town Planned Protection		Art-risk-2 focuses analysis on the building and its content	
	Population		6.4	Population

In order to evaluate these differences with a real case, we hereby present the comparative study of 3 churches in Seville (Spain) – San Lorenzo, San Román and San Andrés – using both methods (Art-Risk-1 and Art-Risk-2). .

3. RESULTS

San Andrés, San Lorenzo and San Román are Gothic-Mudejar churches dating from the 14th Century, located in the historic city of Seville (Spain), established as parish churches after their recapture in 1248.

The main materials employed in the structures of these monuments were bricks, mortar, calcarenite and limestone (Colao et al., 2010). Marble was used for ornamentation and coverings. Brickwork with mortar covering provides the vertical supporting structures. There are also horizontal wooden coverings with jointed rafters, and a finishing layer consisting of ceramic tiles on top. Stonework is located in the main doors, towers and corners. The foundations are made using continuous ditches of bricks or stones (Ortiz and Ortiz, 2016). Figures 1-3 provides general views of the monuments, planes of floor and elevation.

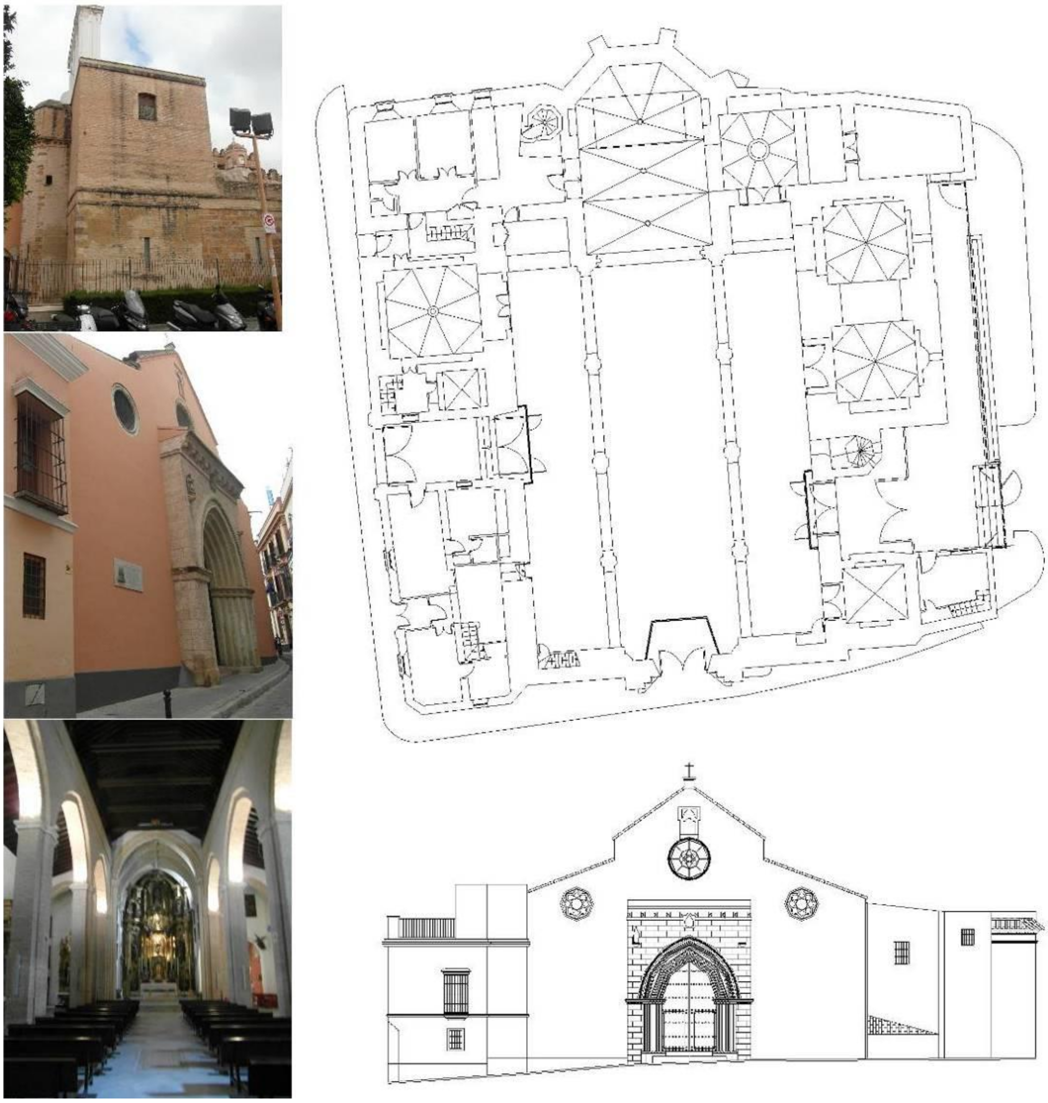

Figure 1. General views of San Andres. Planes of floor and elevation (PEPCH Sector 8.2 San Andrés-San Martín).

Figure 2. General views of San Lorenzo. Planes of floor and elevation (PEPCH Sector 9 San Lorenzo-San Vicente).

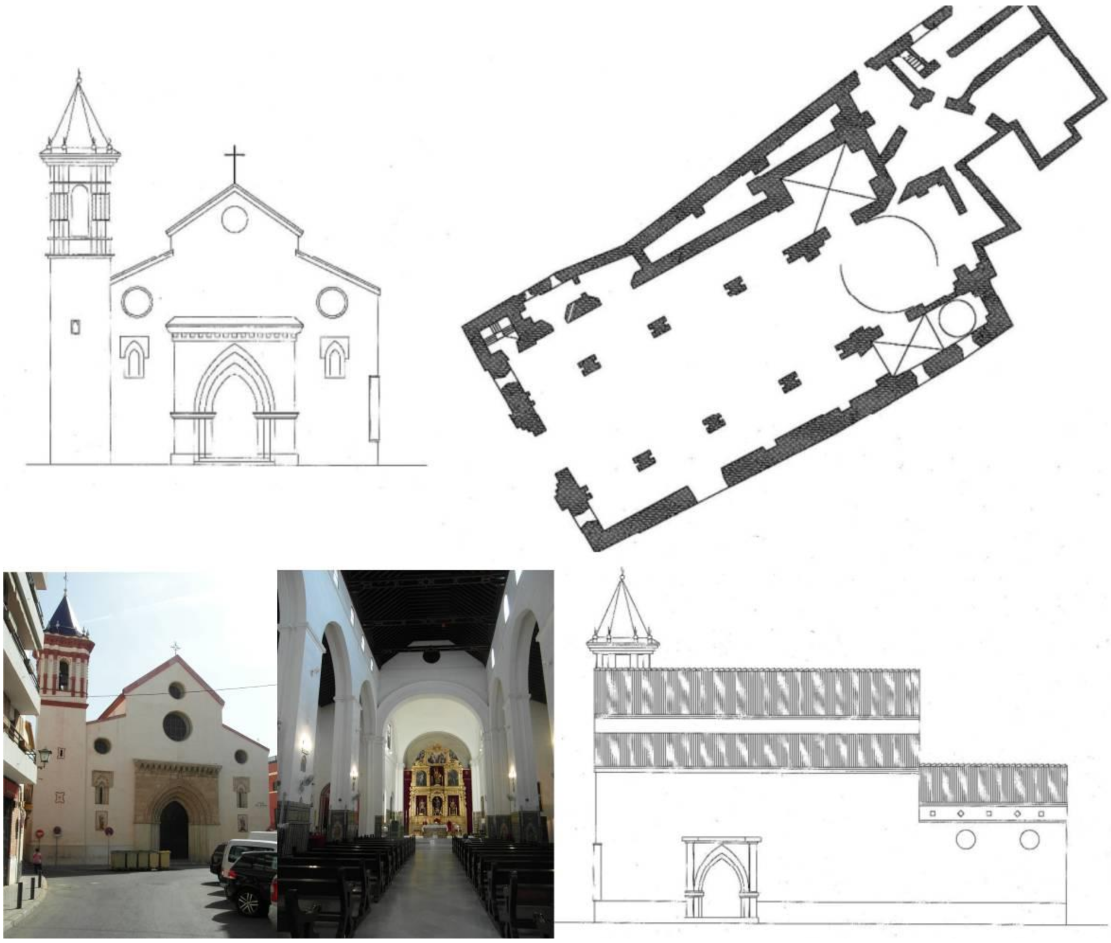

Figure 2. General views of San Román. Planes of floor and elevation (San Román PEPCH Sector 3 Santa Paula-Santa Lucía).

According to the weathering test, the mortar and lithotypes used in Seville are very vulnerable to fire, salt crystallization and traffic. Visual inspection shows that the mortar used to repair stones detaches very easily (Ortiz et al., 2008; Ortiz et al., 2010; Ortiz et al., 2012; Ortiz et al., 2013b; Escudero et al., 2011; Ruiz et al., 2011).

For Art-Risk-1, visual Inspection was conducted on site, analyzing frequency and damage level of weathering forms, along with interviews with stakeholders (owners, priest, sacristan, brotherhood members, …), in order to ascertain the relationship between pathologies and agents. These studies were completed with a characterization of materials and weathering forms in the Cultural Heritage Diagnosis laboratory of Pablo de Olavide University. External references were consulted for the study of protection level, restoration measures, maps, orientation, etc., according to the methodology described by Ortiz et al (2016).

For Art-Risk-2, visual inspection was conducted on site, analyzing the degree of conservation, along with interviews with stakeholders (owners, priests, sacristans, brotherhood members, …) in order to ascertain the relationship between risks and vulnerability factors. External references were consulted for the study of protection level and hazards according to the methodology described by Macías-Bernal (2012).

Vulnerability index (Vi%), expanded vulnerability index (Vie%) and fuzzy building service life (FBSL) are shown in table 3 in order to compare methodologies.

Table 3. Vulnerability index (Vi%), expanded vulnerability index (Vie%) and fuzzy building service life (FBSL) of San Andrés, San Lorenzo and San Román Churches

	VI (%)	Vie(%)	FBSL (years)
San Román	13	11	38
San Lorenzo	16	16	42
San Andrés	27	23	35

San Andres Church has the highest vulnerability index (VIe: 23%), which corresponds with the lowest functionality values (FBSL: 35 years) and the highest values of roof design and constructive system (figure 4.C). Both methodologies concur that San Andres Churches should be the first monument to take into account for preventive conservation monitoring in spite of its low degree of vulnerability.

Both models take into account the constructive system, whereas roof design is only studied for FBSL (table 2). San Andres has the highest level of vulnerability due to its roof design, with a value of 3.6 (figure 4.C), which increases its FBSL value.

The San Roman Church was recently restored, and for this reason its vulnerability indexes (VI and Vie) are the lowest with values between 13-11%, respectively. In spite of its low vulnerability, and low roof design and constructive system values, this church has a lack of forced ventilation that, when combined with the influence of hazards, generates the second lowest FBSL index, with 38 years.

San Lorenzo presents an intermediate-low value on the vulnerability indexes (16%) due to its medium-high degree of conservation, with good ventilation that corresponds with the highest FBSL value (42 years).

Flooding and damp hazards are the most significant threats in Seville (Ortiz et al. 2016b) (figure 4,B). Looking at the hazards of dampness for the three churches, San Roman is located in the zone with the lowest level of risk while San Lorenzo is located in the highest risk area. Dampness damage is assessed in both models, and as San Roman has the lowest risk, it seems that ventilation may be the cause of the differences.

The three churches have a low degree of vulnerability, which means that no direct action is required (Ortiz and Ortiz, 2016), but instead a preventive conservation plan that may cost 10-15 euros/m^2/year.

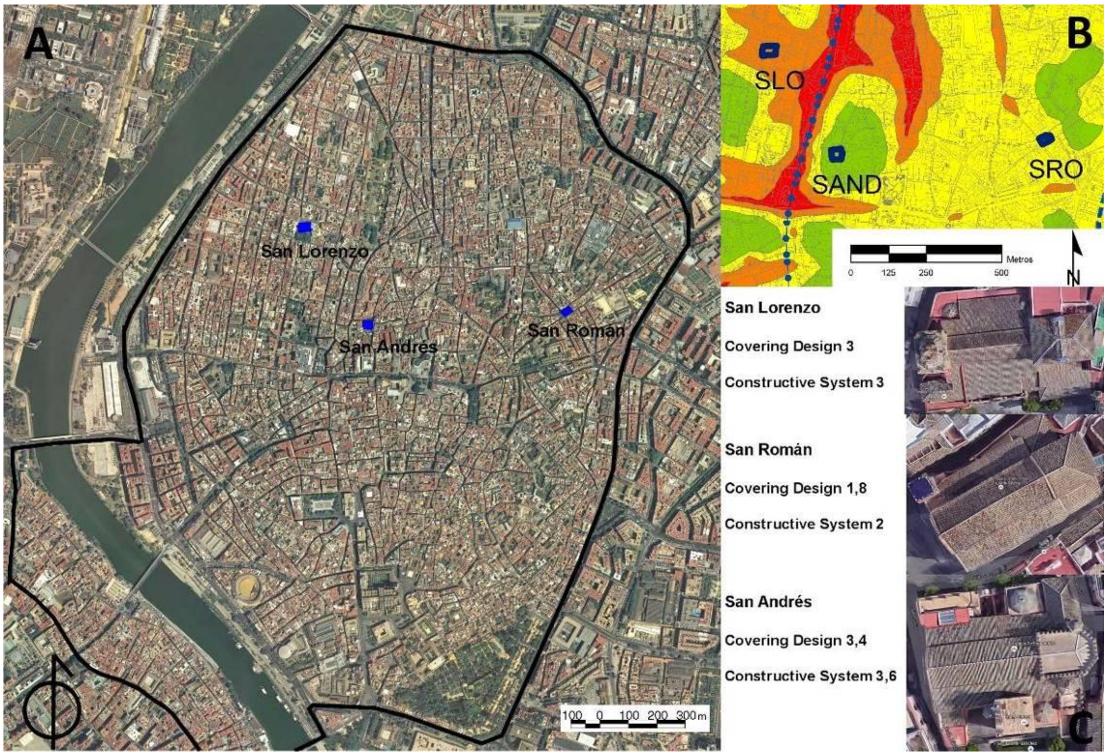

Figure 4. A) General location of San Andrés, San Lorenzo and San Román churches in the historic city of Seville. B) Hazard map of capillarity of the zone, C) General overview of roof and evaluation of roof design and constructive system according to Macías-Bernal (2012)

In summary, both methodologies - vulnerability and service life - are complementary, and the benefits and drawbacks highlighted in this paper for each model are summarized in table 3.

Actions to be taken in the three churches depend on the uncertainty of the methods (Ortiz and Ortiz, 2016). For this reason, further studies are being carried out to evaluate the accuracy and the reproducibility of the methods.

Table 4. Pros and Cons of Art-Risk 1 & 2

Model	Pros	Cons
Art-Risk-1 Delphi Method	General Information Fast and inexpensive methodology Capable of classifying interventions and preventive conservation Priority for restoration Risk and vulnerability are separate	Sampling Problems of incorrect inferences Experts needed for surveys, in-situ diagnosis and science monitoring Mathematical development Ventilation is not directly included

	Variables are geo-referenced in maps by GIS	
Art-Risk-2 Fuzzy Method	General Information Fast and inexpensive methodology Capable of classifying interventions and preventive conservation Priority for restoration No sampling Possibility of time series	Problems of incorrect inferences Experts needed for in-situ diagnosis Mathematical development Risk and vulnerability are mixed Functionality indexes are not the same as actual service life Seismic, landslide, floods, coastal dynamics, avalanches, volcanoes and underground water influence are not directly studied

4. CONCLUSIONS

This new procedure compiles and reflects the key milestones accomplished with regard to vulnerability and service life to provide scientific criteria to develop policies for decision-making to preserve historic centers. Vulnerability indexes and fuzzy building service life are recognized as an innovative methodology that includes multi-scenario analysis and experts' opinion in cultural heritage maintenance. Both methods allow risk to be compared between different cities in order to analyze strategies for cultural heritage conservation in a region, or a city, to evaluate the hazards of different zones in order to plan interventions.

The vulnerability or functionality indexes combined with risk assessment, while limited in accuracy, are coherent and allow for comparisons between diverse monuments.

This study is useful for stakeholders, including SMEs and policy-makers, as an important reference on diagnosis, including updated, inexpensive and sustainable methodologies to manage the preservation of monuments, which are easy to use in developed and developing countries.

The application of vulnerability and/or service life indexes based on artificial intelligence and Delphi assessment to prioritize preventive conservation actions is fundamental to sustainability and to improve the maintenance of cultural heritage buildings.

Future studies should examine the uncertainty of the results in relation to the methods and the maintenance budget.

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